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Time and Workload Analysis to Determine Total Labor in the Arabica Coffee Harvesting Process

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ABSTRACT

Farmers verify ripe coffee cherries, pick them individually, and place them in the harvest basket in the coffee harvesting process. This task typically takes 7-8 hours. During harvesting, farmers experience a physical workload that impacts their work capacity. This research aims to measure the qualitative and quantitative workload levels of the coffee harvesting process, determine the working time based on the farmers' Human Output Capacity, and calculate the total number of daily workers needed to achieve daily coffee production targets. The determination of the number of daily workers is based on the work capacity of the farmers. Farmers were categorized into two age groups: productive age (30-40 years) and non-productive age (50-60 years). Data observed included heart rate during harvest, heart rate calibration data, subjects' body characteristics, and coffee productivity. The results showed that the heaviest workload, related to verifying ripe cherries, fell into the medium category, with an energy consumption level of 3,370 Kcal per minute. The optimal working time for the coffee harvesting process is 6 hours for workers of productive age and 4 hours for workers of non-productive age. To meet production targets, 9 workers of productive age and 10 workers of non-productive age are required.

1. Introduction

Coffee is one of the plantation commodities widely consumed by the community. Indonesia is one of the largest coffee-producing countries, capable of producing 786,991 tons of coffee (Saolan *et al*., 2020). This production can generate foreign exchange income of 858.558 million USD (BPS, 2021). Exporting is the primary business activity for most coffee companies due to the high selling value of coffee. Therefore, to support sustainable export activities, it is necessary to increase coffee productivity to meet the growing demand. One crucial aspect of enhancing coffee productivity is the harvesting process.

Coffee harvesting involves picking coffee cherries from trees that are 2.5 to 3 years old. In Indonesia, coffee harvesting is still done conventionally by hand-picking the cherries (Prastowo, *et al*., 2017). This method ensures the production of high-quality coffee cherries with uniform quality. During the harvesting process, farmers walk through the garden, picking cherries one by one and placing them in a harvest basket for 7 to 8 hours. However, this process imposes a physical workload on farmers, impacting their productivity. An appropriate physical workload that matches the farmers' capacity will result in optimal productivity (Fil'aini & Sari, 2020).

A physical workload that exceeds the body's capacity negatively impacts health. Farmers may experience fatigue during the harvesting process, leading to decreased productivity. Physical workload can be analyzed based on physiological indicators such as heart rate, body temperature, muscle work, and oxygen consumption. Heart rate is a particularly easy and effective indicator to measure. Monitoring heart rate during the coffee harvesting process can reveal whether the workload is too high. A fast heart rate indicates a high workload.

Workload measurement is divided into two categories: qualitative workload and quantitative workload. Qualitative workload is assessed based on fatigue levels, while quantitative workload is determined by energy consumption levels (Bary *et al*., 2013). Workload is also influenced by physiological factors such as age, gender, and health conditions (Fil'aini & Sari, 2020). These factors affect heart rate performance and, consequently, work capacity (Syuaib *et al*., 2002). Therefore, it is essential to measure workload to determine optimal productivity levels and work time, ensuring farmers do not experience fatigue and decreased productivity. Optimal work time is the time required for each worker to complete their tasks efficiently (Sari *et al*., 2023).

Serious injuries can result in musculoskeletal disorders (MSD), leading to absenteeism, reduced work capacity, and early retirement, which create a significant burden on individuals, workplaces, and communities worldwide (Jakobsen *et al*., 2018). Poor process design can result in excessive physical workload, ultimately reducing performance and job satisfaction (Chenarboo *et al*., 2022). One method to improve work process design is determining the optimal work time (Muti *et al*., 2022). Optimal work time facilitates the determination of the ideal number of workers needed, thereby enhancing productivity (Sari & Nurfida, 2022).

This study aims to measure the qualitative and quantitative workloads in the coffee harvesting process, determine the optimal work time, and identify the total number of daily workers needed to achieve optimal coffee productivity.

2. Methods

2.1 Material

The tools and materials used in this study include Heart Rate Monitors (HRM), digital cameras, worksheets, stopwatches, scales, and meters. The processing process is carried out using data processing software in the form of Microsoft Excel and data reader software in the form of Polar Flow software.

2.2 Research Methods

The research was conducted on coffee plantations in the Pangalengan area, West Java. This province produced 23,100 tons of coffee in 2021. The subjects studied were coffee farmers who were accustomed to the coffee harvesting process and in healthy physical condition. The subjects were classified into two groups: farmers aged 30-40 years as the productive age group, and farmers aged 50-60 years as the non-productive age group.

The research process was divided into three stages: the preliminary stage, data collection, and data processing. The preliminary stage involved conducting site surveys, observing work elements, and preparing for data collection. The data collection stage involved gathering heart rate data during coffee harvesting and calibration, collecting subjects' body characteristics data, recording harvesting time, and measuring production weight.

The subjects were calibrated using the step test method for three cycles: 15 cycles/minute, 20 cycles/minute, and 25 cycles/minute (Fil'aini & Sari, 2020). Each cycle included a five-minute rest period. The calibration process was conducted to determine the correlation between heart rate and workload. The step test process can be seen in Figure 1. After the calibration process, heart rate data were collected during the coffee harvesting process. The subjects were fitted with heart rate monitors (HRM) during the harvesting process, and data collection was stopped after the subjects completed three elements of work.

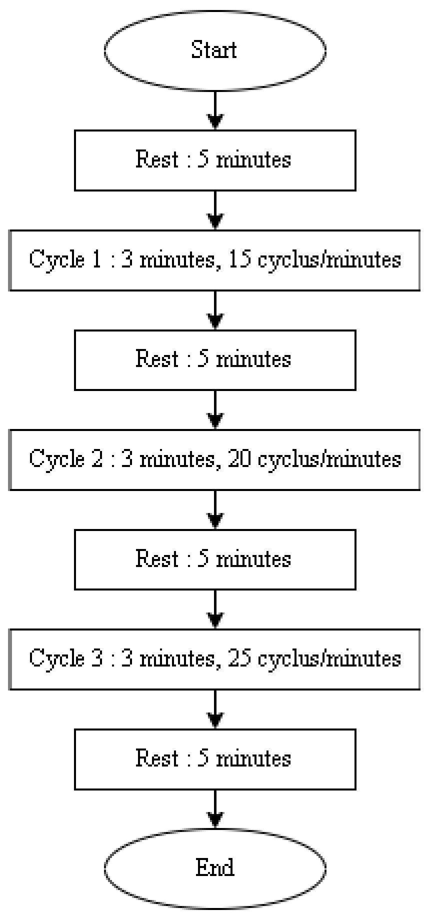

Figure 1. Calibration data capture flow (Fil'aini & Sari, 2020)

At the data processing stage, Basal Metabolic Energy (BME) values are calculated according to the subjects' body characteristics of each subject using the Du'Bois equation (Equation 1). The BME (Kcal/min) is the value resulting from the conversion of body surface area divided by 200 (Bary *et al*, 2013).

$$A = H^{0,725} \times w^{0,425} \times 0,00724 \quad (1)$$

$$IRHR= \frac{\text{HR } Work}{\text{HR } Rest} \quad (2)$$

where the value of A is the surface area of the body (m^2), H is the height of the subjects' body (cm), w is the subjects' weight (kg), IRHR is the Increase Ratio of Heart Rate, and HR is the heart rate (bpm).

After the BME value is obtained, the BME value conversion is carried out based on Table 1 (Syuaib, 2003). The next step is to transfer the heart rate value to a computer using Polar Flow software for data processing and graphing. The heart rate value is subjective by comparing the heart rate at work and the heart rate at rest (Equation 2). IRHR value categorized by workload category can be seen in Table 2 (Syuaib, 2003).

Table 1. BME conversion by body surface area (equivalent to $\dot{\boldsymbol{VO}}_{\boldsymbol{2}}$)

L/100 m^2	0	1	2	3	4	5	6	7	8	9
1,1	136	137	138	140	141	142	143	145	146	147
1,2	148	150	151	152	153	155	156	157	158	159
1,3	161	162	162	164	166	167	168	169	171	172
1,4	173	174	176	177	178	179	181	182	183	184
1,5	186	187	188	189	190	192	193	194	195	197
1,6	198	199	200	202	203	204	205	207	208	209
1,7	210	212	213	214	215	217	218	219	220	221
1,8	223	224	25	226	228	229	230	231	233	234
1,9	235	236	238	239	240	241	243	244	245	246

Table 2. Level category of IRHR Value

Level category	IRHR value
Light	$1.00 \leq IRHR < 1.25$
Medium	$1.25 \leq IRHR < 1.50$
Heavy	$1.50 \leq IRHR < 1.75$
Very heavy	$1.75 \leq IRHR < 2.00$
Unbelievably heavy	$IRHR \geq 2.00$

Apart from calculating the BME value, the subjects' body characteristics are also used to calculate the WEC value. The calculation of the value of energy consumption when doing a step test can use Equation 3.

$$WECst= \frac{w\times g\times 2f\times h}{(4{,}2\times 10^{3)}} \quad (3)$$

where WEC is work energy cost (Kcal/minute) w is the subjects' weight (kg), g is the gravity of the earth (m/s^2), f is the step test cycle, and h is the height of the step test bench (m). The WECst value obtained is correlated with the IRHR value so that a regression equation (y = ax + b) is obtained, where y is the IRHR and x is the WEC value. The regression equation will then be substituted with IRHR when doing work to get the WEC harvesting work.

The BME and WECwork values obtained are added together to obtain the total energy cost (TEC) for each subject. The TEC obtained will be divided to the weight of each subject to obtain a normalized total energy cost (TEC'), so that the weight of each subject affects the rate of work energy cost. The value of TEC represents the total energy consumption per weight (Kcal/minute.kg). Furthermore, the rate of TEC is calculated using Equation 4.

$$\overline{TEC'} = \frac{\Sigma TEC'}{n} \times \frac{\Sigma w}{n} \quad (4)$$

where $\overline{TEC'}$ is rate of total energy cost (Kcal/minute), TEC' is the rate of total energy cost per weight (Kcal/minute.kg), w is the subjects' weight (kg), and n is the number of subjects. Value $\overline{TEC'}$ is used to find the value of energy expenditure (Ex) with Equation 5.

$$Ex = \overline{TEC'} \times \left(\left(\frac{\Sigma tn}{m}\right) + \left(\frac{\Sigma tp}{m}\right)\right) \quad (5)$$

where t_n is normal time (minutes), t_p is adjustment time (minutes), and m is the subjects' weight (kg). The value of *energy expenditure* (Kcal/kg) obtained is compared with the value of *Human Output Capacity* (HOC) so that the value of work capacity (Wc) is obtained using Equation 6.

$$Wc = \frac{HOC}{Ex} \quad (6)$$

The value of the work capacity obtained will be compared with the daily production target (Y) to get the total workers. Total workers are needed to achieve daily production targets. Calculation of total workers using Equation 7.

$$\text{Total workers} = \frac{Y}{Wc} \quad (7)$$

where Y is daily production target (kg/day/person), Wc is work capacity (kg/day), HOC is human output capacity (Kcal/day)

Determination of the optimal time of work is carried out based on the calculation of the rate of total energy cost. The optimal work time is affected by HOC and TEC' so that work time can be obtained using Equation 8 where t_{kmax} is the optimal work time (hours).

$$t_{k\,max} = \frac{HOC}{\overline{TEC'} \times 60} \quad (8)$$

3. Results and Discussion

Heart rate calibration is a method used to determine the correlation between the value of energy produced and heart rate. The calibration process is carried out using the step test method on each research subject. The energy value produced is influenced by physical characteristics and the number of cycles during the step test. From the correlation between heart rate and energy consumption value, a regression equation can be derived, as shown in Figure 2. Based on the resulting regression equation, the correlation between heart rate and energy produced is positive. An increase in workload causes an increase in heart rate. The relationship between heart rate and energy consumption can be seen in the regression equation, where the slope value represents the coefficient α in the equation $y=\alpha x+\beta$. The largest slope value is found in subject 2 (P2), with a slope value of 0.3203. The regression equation shows that a steeper slope indicates a greater increase in heart rate with each increase in workload. The resulting regression equation is used to find the value of energy consumption during harvesting by substituting heart rate data into the equation, producing the value of energy consumed (Fil'aini & Sari, 2020). The Increase Ratio of Heart Rate (IRHR) during harvesting can be seen in Table 3.

Based on Table 3, a qualitative assessment of workload is obtained based on the level of fatigue, which is categorized by the IRHR value. The lowest level is found in the cutting work element, with a value of 1.013, indicating a light workload. The highest level of qualitative workload is found in the transport work element, with a value of 1.379, indicating a medium workload.

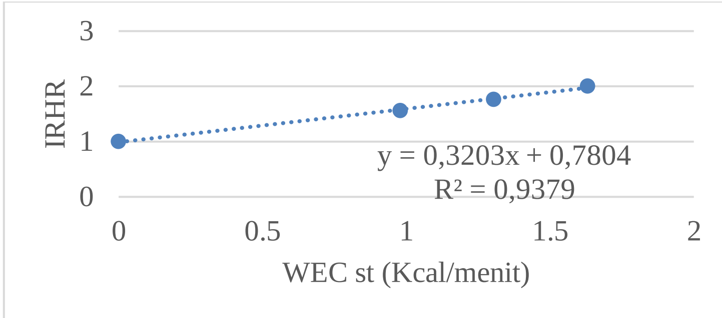

Figure 2. Correlation between IRHR and WECst

Table 2. IRHR value for each subject

Subject	Verification		*Cutting*		Shuttle	
	IRHR	Level Category	IRHR	Level Category	IRHR	Level Category
P1	1,169	Light	1,095	Light	1,239	Light
P2	1,161	Light	1,045	Light	1,379	Medium
P3	1,152	Light	1,060	Light	1,161	Light
P4	1,231	Light	1,013	Light	1,254	Medium

The difference in heart rate values in each work element is caused by the work activities carried out. The load received during the transport work element is greater than that during the cutting work element (Fil'aini & Sari, 2020). The transport work element involves more displacement activity compared to the cutting work element. The steep terrain conditions during the transport process, as well as the body characteristics of each subject, also affect the resulting increase in heart rate. Subjects P1 and P2 had fitter physical characteristics with a productive age classification, while subjects P3 and P4 had a non-productive age classification. Significant age differences cause differences in energy produced; increasing age leads to a decrease in physical condition and limited energy availability, resulting in a lower heart rate (Fil'aini & Sari, 2020). The higher the heart rate value produced, the greater the energy consumed. The resulting qualitative workload is directly proportional to the quantitative workload. The energy consumed by each subject can be seen in Table 4.

Table 3. Total energy cost for each subject

Subject	TEC verification (Kcal/Minute)	TEC *cutting* (Kcal/Minute)	TEC shuttle (Kcal/Minute)
P1	2,457	2,064	2,835
P2	2,222	1,861	2,903
P3	2,135	1,808	2,169
P4	3,212	1,727	3,370

Based on the results of the study, the lowest quantitative workload was found in the cutting work element, with a value of 1.727 Kcal/minute, while the highest quantitative workload was found in the transportation work element, with a value of 3.37 Kcal/minute. The difference in the rate of energy consumption is due to physiological conditions and the weight of production for each subject (Fil'aini & Sari, 2020). In the transportation work element, each subject carried 7-10 kg of coffee cherries. The production load causes the subjects to expend more energy to carry out transport activities compared to the cutting work element.

Energy expenditure is the amount of energy that workers devote to completing an activity. The rate of energy consumption and the standard time affect the value of energy expenditure. The value of energy expenditure is presented in Table 5.

Table 4. Acquisition of energy expenditure value and work capacity

Subject	Work elements	$\overline{TEC'}$ (Kcal/minute)	Standard time (minute/kg)	*Energy expenditure* (Kcal/kg)	Work capacity (kg/day)
P1 dan P2 (Productive Age)	Verification	2,345	15,355	36,009	18,129
	Cutting	1,967	58,072	114,246	5,714
	Shuttle	2,871	3,394	9,744	66,993
P3 dan P4 (*Non-productive* age)	Verification	2,661	17,866	47,544	9,591
	Cutting	1,770	49,244	87,185	5,230
	Shuttle	2,756	4,666	12,858	35,465

According to the result from Table 5, it can be seen that the raw time produced is greater than the rate of energy consumption. This indicates that the coffee harvesting process has a higher level of difficulty compared to the workload level. The highest energy expenditure value is found in the cutting work element while the lowest energy expenditure value is found in the transportation work element. The difference in energy expenditure value is caused by significantly different standard times. Cutting work elements requires a longer raw time compared to transporting work elements. This indicates that the cutting work element has a higher level of work difficulty compared to the transportation work element (Fil'aini & Sari, 2020).

The value of energy expenditure produced is inversely proportional to the work capacity produced. The higher the value of energy expenditure will result in a low daily work capacity value. Based on the Table 5 Subjects of productive age produce greater daily work capacity compared to non-productive age. The largest daily work capacity is found in the transportation work element while the smallest daily work capacity is found in the cutting work element. This indicates that achieving production targets requires a higher work capacity in cutting work elements. The resulting work capacity affects the total number of workers needed to achieve production targets (Fil'aini & Sari, 2020). The total number of workers required can be seen in Table 6.

Based on Table 6, the correlation between daily work capacity and total workers is inversely proportional. The greater the work capacity produced, the greater the total need for workers to achieve daily production targets. The highest total number of workers was obtained in non-productive age workers with a total of 10 workers. The total number of workers required at productive age is 9 people. The difference in total workers in age classification is due to the resulting work capacity. The smaller work capacity causes the total need for workers to be greater. The determination of the total workers is carried out on the results of cutting work elements because the coffee harvesting process is dominated by cutting work elements. The physical condition of a non-productive age that is not optimal causes the daily work capacity produced to be small. Therefore, more total workers are needed to achieve the daily production target.

Table 5. Total workers needed

Work elements	Production targets (kg/day)	Subject	Daily work capacity (kg/day/person)	Total workers (person)
Verification	50	P1 dan P2 (Productive Age)	18,129	3
	50	P3 dan P4 (Non-productive age)	9,591	5
Cutting	50	P1 dan P2 (Productive Age)	5,714	9
	50	P3 dan P4 (Non-productive age)	5,230	10
Shuttle	50	P1 dan P2 (Productive Age)	66,993	1
	50	P3 dan P4 (Non-productive age)	35,465	1

In achieving maximum productivity, working hours are needed in accordance with the capacity of the human body. Excessive working hours cause burnout in workers and decrease work productivity. Working hours that are in accordance with body capacity make workers more optimal at work, do not experience fatigue, and produce work comfort. The determination of work time is carried out based on energy consumption, human output capacity, and work time in Table 7.

Tabel 6. Optimal uptime based on workload

Subject	Work elements	*Human output capacity* (Kcal/day)	$\overline{TEC'}$ (Kcal/minute)	Working time (Hour)
P1 dan P2 (Productive Age)	Verification	652,8	2,345	5
	Cutting		1,967	6
	Shuttle		2,871	4
P3 dan P4 (*Non-productive* age)	Verification	456	2,661	3
	Cutting		1,770	4
	Shuttle		2,756	3

According to Table 7, cutting the work element requires the longest work time, which is 6 hours of work for productive age and 4 hours of work for non-productive age. The greater the rate of energy consumption, the less work time is produced so that you do not experience fatigue. The determination of work time is carried out based on the elements of cutting work because the harvesting process is dominated by cutting activities. The difference in working hours is caused by age factors that affect HOC. As humans age, it causes a decrease in HOC in humans. The difference in working hours is also caused by physical conditions in humans. The older the age, the more a decrease in the performance of physical condition so that it is faster to experience fatigue in old age. Based on observations, farmers carry out the coffee harvesting process for 7-8 working hours. These working hours exceed the limit of calculation results based on energy consumption, so workers experience fatigue due to excessive working hours. Working hours that are too long and repetitive work also cause a decrease in concentration in workers so that productivity is not optimal. This statement is supported by (Rizqi *et al*., 2019) research which states that the average coffee harvesting is carried out for five hours per day, so it is necessary to improve working hours.

4. Conclusions

The highest qualitative workload has an IRHR value of 1.379 with a medium workload category in the transport work element, while the lowest qualitative workload has an IRHR value of 1.095 with a light workload category in the cutting work element. The highest quantitative workload has a TEC value of 3,370 kcal/min in the transport work element and the lowest TEC value of 1,727 Kcal/minute in the cutting work element. Based on the results of energy consumption, the allowed work time for the productive age is 6 working hours with a total of 9 farmers, and for the non-productive age is 4 working hours with a total of 10 farmers.

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6. Authors Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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